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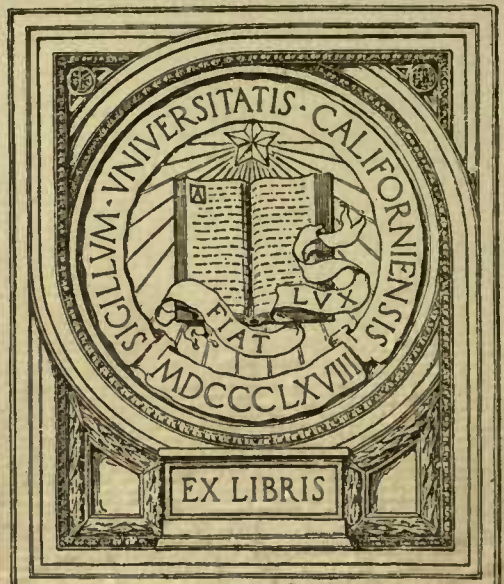

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The following is reprinted from **Gailiard's Medical Journal,** *and though by no means the strongest portion of the work, since it is not so demonstrative, will excite, perhaps, the most lively interest in the profession.*

MECHANICAL PRINCIPLE IN THE CIRCULATION IN THE EMBRYO: PLACENTAL SOUFFLE THE ANALOGUE OF RESPIRATION.

RESPIRATION IN THE NEW-BORN: THE CHANGE IN MECHANICS WHICH THIS INVOLVES.

INCUBATION: THE RELATION THIS SUSTAINS TO THE AIR-CHAMBER IN THE EGG.

MODE OF GRAFTING THE OVUM IN THE TISSUES OF THE WOMB.*

BY W. H. TRIPLETT, M.D., WASHINGTON, D. C.

WE have seen that respiration and circulation must be treated together, since they form *a connected movement* for pumping the commerce in and through the organism for elaborating structure and evolving force, and that the whole is founded in the power of producing rhythmical changes in pressure, the fluids flowing from high to low pressure in conformity with organic law; that the lungs, intestines and bloodvessels are necessarily allied in respiration in order to make importation and transportation a connected movement between the cell-brood and environment, which the scheme calls for. In other words, that the *pumping action* in respiration *compels* the commerce in the vessels, while the action in the heart, arteries and venous system circulates it through the organism, the action being unified throughout by means of the nervous combinations in the medulla oblongata, in which the respiratory, vaso-motor and voluntary motor centres, are correlated, the one calling for the other, as has been fully set forth in the preceding pages, and that the vital phenomena, anatomical and physiological, appertaining to respiration, circulation absorption, etc., are readily explained and accounted for, giving absolute proof of the correctness of the premises, as before remarked. We now follow this matter a little further, and take up

CIRCULATION IN THE EMBRYO,

a subject which, it must be admitted, is at present veiled in deep obscurity. This is nevertheless susceptible of explanation. The embryo is an *aquatic*

* From a manuscript work being prepared for publication, entitled "Natural Philosophy of the Body; or, the Mechanics in Respiration, Circulation Absorption, Etc.," chapters XVI. and XVII.

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animal, since it leads a subaquatic existence, being placed under water (Fig. 1) and deeply buried in the maternal tissues, which would account for the peculiarities that obtain in its circulation approximating it to the stages in development represented in fishes and amphibia.

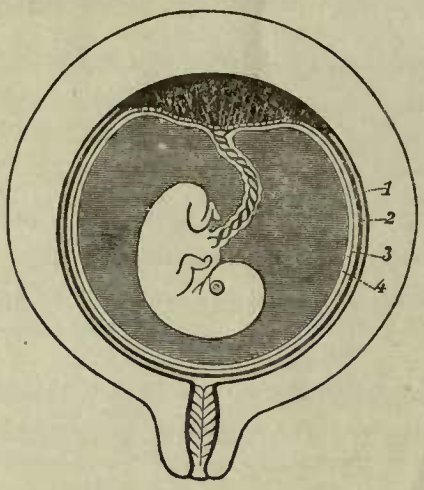

FIG. 1.—GRAVID HUMAN UTERUS AND CONTENTS, showing the relations of the cord, placenta, membranes, etc., about the end of the seventh month. 1, decidua vera; 2, decidua reflexa; 3, chorion; 4, amnion. (After Dalton.)

The physical conditions under which the embryo is evolved determine the special vascular arrangements for effecting circulation, while the transformations which accompany this provide for the radical physical changes which are ushered in at the end of the term, when it becomes an air-breather, the fundamental circumstance underlying it all being *an adjustment with pressure, and the power of effecting rapid rhythmical changes in pressure*, or of producing the universal pumping actions going on in the body. For example, we have seen that the rhythmical expansions and contractions pervading the body in the air-breather, and known as *respiration*, compel oxygen and aliment in the circulatory apparatus for evolving force and producing growth; so, in like manner, a similar necessity exists in the embryo for compelling the nutritive and force-producing elements in its circulation for producing growth and evolving force, which is principally expended in elaborating its structures. But since the embryo feeds in the uterine sinuses from which the commerce is obtained, and into which the waste products are returned, this calls for the differentiation of the special organ known as the placenta, and which answers to the more highly differentiated lungs and intestinal canal which are to substitute it at the end of the intra-uterine term as the relative adjustments with the larger environment, lower pressure, and higher order and amount of work which this involves.* The placental souffle, then, which is distinctly heard through the maternal structures is the analogue of respiration in the air-breather, the relative ratio of the movements to the pulsations in the fœtal heart

* For further particulars, see Part II. of this work, "On the Relation of Gravitation to Development," to be issued shortly.

being also the same, or as 1 to 4 of the latter, whilst the villi are the analogues of the villi is the intestinal canal, the one being submerged in the sinuses, the other in the juices in the intestine. Since the pumping action in respiration is absolutely essential for compelling the commerce in the vessels, it follows that this circumstance should be represented in the embryo, as the maternal blood does not enter the embryo, the latter feeding out of the sinuses simply by means of the villi in the placenta, and this pumping action spoken of; for here, as elsewhere in the body, there are no means for increasing circulation but by *rhythmical changes in pressure*. The result must then be the action in the placenta simulating respiration. The relative frequency of this movement to the action taking place in the fœtal heart is as 1 to 4, or the same as in respiration.

Thus, in the case of the placental souffle it is 30 to 35, and in the fœtal heart the pulsations are from 120 to 140 per minute; while, in the case of the air-breather, the pumping action in the trunk or respiration is from 16 to 20, and in the heart from 60 to 80 per minute. Again, this action in the placenta serves not only to pump the fluids in and out of the sinuses, but at the same time it also aspirates the venous blood in the embryo for effecting oxygenation in it the same as obtains in the lungs: the heart and vessels assisting in the one as well as in the other, since it all forms a connected movement. We now see that by reason of the great increase in pressure that obtains in the embryo, the action in the organs for changing pressure is materially assisted, since the fluids flow more readily in consequence. And here comes in the benefit of the amniotic fluid, which not only increases pressure in proportion, but at the same time it serves to transmit the force in the placenta and uterine walls to the embryo for compelling corresponding changes in pressure upon the blood in connection with the special functions.

As illustrating this fact, we see that when the placenta expands for aspirating the fluids in the uterine sinuses, the organ advances into the uterine cavity, it swells out and occupies more room, and, by thus encroaching upon the embryonic area, it produces corresponding increase in pressure upon the liquor amnii and embryo, with low pressure in itself, which fulfils the conditions for increasing circulation from the embryo to the placenta, at the same time, that it should aspirate the fluid in the uterine sinuses. It could not do otherwise in the very nature of things. During contraction in the placenta, the opposite conditions should obtain, since this would determine high pressure in the latter with low pressure in the embryo, the blood in consequence flowing through the umbilical vein with augmented speed, and for the reason that contraction should reduce the volume of the placenta, which would inevitably reduce pressure in the embryo in proportion, the blood flowing from one into the other in conformity with organic law. To this, again, must be added the action in the heart for aspirating the blood in the placenta. The media in which the animal lives obviates the necessity for the extensive arrangements for reducing pressure in the chest, which obtain in the lighter media of the atmosphere, the heart, together with the force in the placenta and umbilical vein, being sufficient for the purpose.

A subaquatic existence calls for but slight reduction in pressure in order to compel movement; accordingly, we have the blood rushing in and out of the heart as a result of the rhythmical expansions and contractions in this organ; while for increasing this action, the vessels are combined in the mechanics by means of the vaso-motor apparatus, and which, undoubtedly, connects with the action in the placenta. The right ventricle is *thicker* and *stronger than the left*, as adjustment for this mechanics, since the diastoles should aspirate the blood in the two cavæ, while the two systoles would produce high pressure in the arterial system for increasing circulation in the capillaries.

By means of this combined action in the placenta, heart and vessels, a rapid circulation is readily effected under the high pressure that obtains in intra-uterine life; but anything which should interfere with this mechanics by reducing pressure, *e. g.*, escape of the amniotic fluid, would promptly destroy life. How, otherwise, account for this circumstance, since the vascular connections are *uninjured?* Moreover, the lividity of the skin, which occurs in these cases, proves conclusively the existence of venous stasis in the systemic capillaries, and insufficiency of the heart's action to carry on circulation in the absence of the normal pressure upon the embryo. The same circumstance occurs to the air-breather when carried to too great an altitude, notwithstanding the extensive arrangements for changing pressure in the chest, which exist in the latter. This circumstance may be especially noticed in balloonists, and also in persons ascending mountain ranges, respiration and circulation becoming more and more embarrassed as the journey is proceeded with, and venous stasis more and more conspicuous, till the limit of endurance is reached or life itself is terminated, as occurred in the celebrated case at Paris, in which the voyage was made by two balloonists, one losing his life, the other being unconscious when the balloon descended.

THE ACTION IN MEDUSÆ CONTRASTED WITH THE ACTION IN THE PLACENTA.

The action in *medusæ* feeding in the juices in the sea, pumping them in and out of the internal compartments by means of rhythmical expansions and contractions for changing pressure upon them, may be taken to illustrate the mechanical action in the placenta, which feeds in the juices of the womb, pumping them in and out itself from the maternal sinuses. Thus the peduncles (Fig. 2, *a*, *a*, *a*) answer to the tufts while the mantle represents the body of the placenta. But to make the analogy complete, a tubing should project from the convex surface of the latter to represent the umbilical vein and arteries, and which, for obvious reasons, are not present. The analogy is more striking, however, than would appear on the surface, since from the periphery of the stomach a system of radiating canals extends to the edge of the mantle, dividing, subdividing and anastomosing to form a continuous and complicated capillary plexus around the free margin of the mantle, inclusive of the colored lobes, to form the respiratory apparatus. This may be taken to represent the circulation on the distal side of the placenta, and though, for obvious reasons, the force is increased in the embryo, still the mechanical principle is the same for both circulations.

In the mantle, as well as in the placenta, unstriped muscles are present for increasing the energy of the rhythmical expansions and contractions. But muscles are not essential to this action, a notable example of which is furnished in the heart itself, which expands and contracts regularly and rhythmically before a muscle or nerve is developed in the protoplasmic and undifferentiated walls (p. 499), also in capillaries and in early animal forms.

It is interesting to note the fact in this connection (which has already been commented upon in the higher stages of development), that *every movement* of the animal, by extending or retracting the mantle and the branched peduncles, must *necessarily* increase circulation and respiration in correspondence. It could not be otherwise. Numerous stomata in the rounded extremities of the peduncles (*a*, *a*, *a*) afford free ingress and egress to the fluids in the central canals (*b*, *c*).

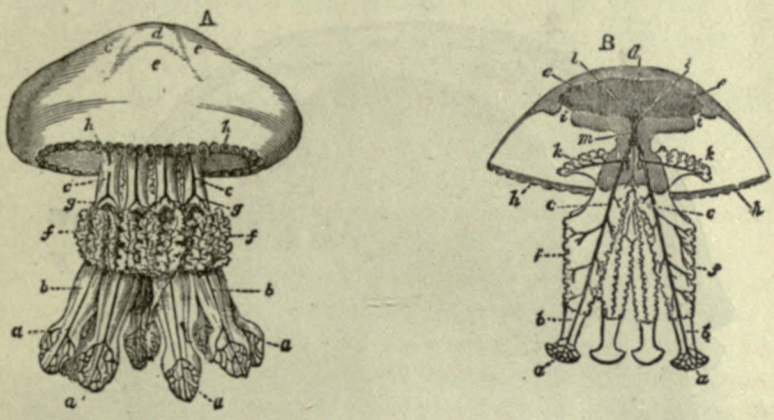

FIG. 2.—MEDUSA (*Rhizostoma cuvieri*). *A*, *a*, *a*, eight peduncles; *b*, *c*, internal canals leading up to the stomach; *d*, stomach; *e*, *e*, *e*, *e*, surmounting ovarial sacs (four); *f*, *k*, lateral respiratory canals; *h*, *h*, respiratory lobes on free margin of mantle (colored); *l*, *l*, thin membranous partitions separating the cavity of stomach from the ovarial sacs; *i*, *i*, external opening to ovarial sacs; *m*, œsophageal passage. (After Grant.)

The capillary loops at the sides of the peduncles (*f*, *k*), which function as absorbent and respiratory vessels, may be taken as the simile of the capillary loops in the tufts of the placenta.

This brief description will serve to explain the mechanical principle in the placenta, and it now remains to be seen how this action is assisted by the action taking place in the womb itself; or how the maternal and fœtal circulations are made to connect for effecting mutual interchange, the former supplying the nutritive and force-producing elements for the growth and elaboration of tissue, the latter yielding up the waste products to be borne back through the maternal channels to the environment from which everything is derived, and into which, in due time, everything is returned in the form of waste products and final dissolution.

MODE OF CONNECTING THE MATERNAL WITH THE FŒTAL CIRCULATION.

The circulation of maternal blood in the uterine and placental sinuses is the same in principle as that for circulating air in the lungs, namely, by rhythmical changes in pressure in the sinuses, which is produced by the action taking place in the womb itself; taking the placental sinuses to represent the alveoli, and the uterine the tracheal system, the blood flowing in and out of this system of canals by reflux action for renewal, just as the pulmonic air flows in and out of the tracheal system for renewal, only that in the former the fluid passes into the venous system of the mother and is returned by the arterial, both terminating by capillary openings in the canals, while the placental souffle answers to the respiratory murmur.

We have already spoken of the *role* which the placenta plays in this respect, and it now remains to take up the very important one which the uterus itself

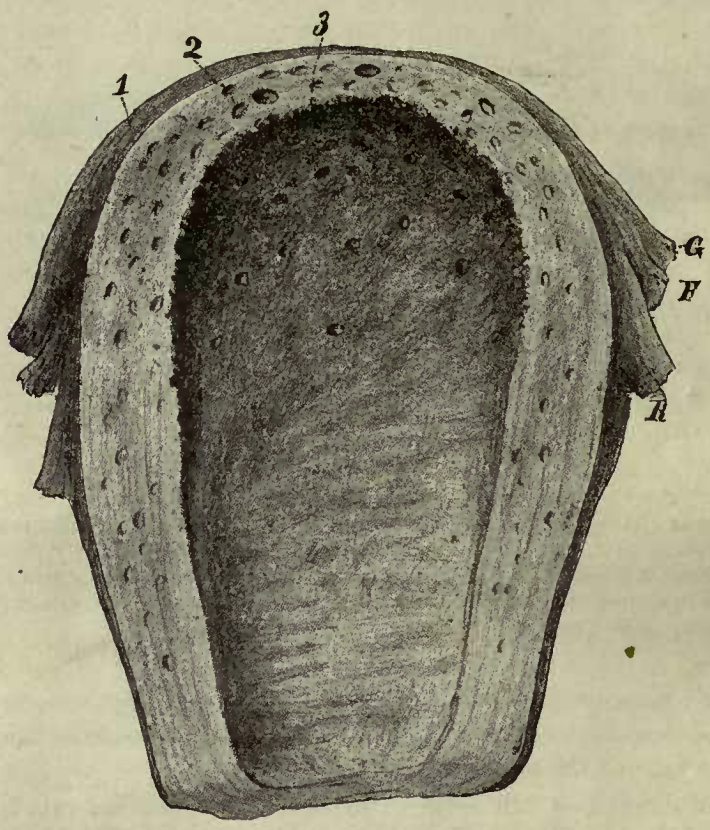

FIG. 3.—LONGITUDINAL SECTION OF A LATELY GRAVID WOMB, showing the canal system. Taken from a case of post partem hæmorrhage (partly diagrammatic). 1, peritonæum; 2, uterine canals (sinuses); 3, openings to canals on the mucous surface corresponding with openings to placental sinuses; *g*, Fallopian tube; *f*, ligament to ~~artery~~ ovary; *r*, round ligament.

performs for completing this deeply-interesting mechanics, which it would be difficult to overestimate, underlying, as it does, embryonic life.

First, with regard to the uterine sinuses, we may mention that this canal

system which is channeled in the walls of the gravid womb does not consist of veins or arteries enlarged for the purpose, but, on the contrary, that the proper substances of the womb itself (muscles and connective tissue) compose the actual walls, which are lined by a delicate membrane answering to the lining membrane of the vessels. The difference is very material, since the vessels are enabled to expand and contract themselves for increasing circulation, while in the case of the sinuses, the walls of the womb would have to expand and contract in order to ~~insure~~ circulation in them, and that this is the case will appear more obvious as we proceed, the mechanics undoubtedly calling for such a condition.

When a longitudinal section is made of a gravid womb at full term, this canal system is seen to traverse its substance in various directions from near the central portions, but trending to the internal or mucous surface where they connect with the placenta (Fig. 3—2, 3). They never penetrate to the external surface to form continuous tubes with the arteries or veins; but on the contrary, both these systems of vessels connect with this system of canals by means of *capillaries*, the arterial emptying and the venous discharging from these common mains. Hence this blood is mixed as a matter of necessity.

The next important point is the method this system of canals exhibits in connecting with the placental sinuses, which is done by *projecting the lining membrane into the substance of the placenta* (Fig. 4, *c*, *c*, *c*, *c*). This spreads out at once

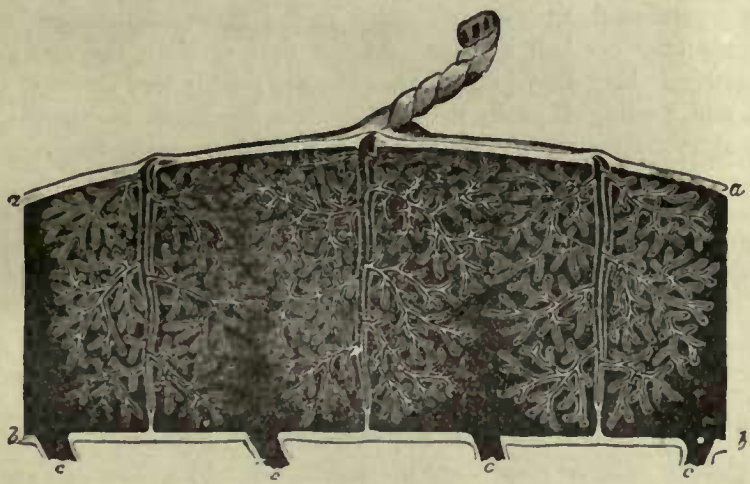

FIG. 4.—VERTICAL SECTION OF PLACENTA, showing arrangement of maternal and fœtal vessels. *A*, *a*, chorion; *b*, *b*, decidua; *c*, *c*, *c*, *c*, orifices of uterine sinuses. (After Dalton.)

to form the large cavitary spaces in which the highly ramified placental tufts are suspended and submerged in blood.

The walls of these large cavities in which the lining membrane of the uterine sinuses is merged answers to the outer surface of these highly-ramified tufts which fit into this as the fingers in a glove, the vascular loops being contained inside of them (Fig. 5, *a*, *a*). It is easy to perceive that this outside wall and the wall of the capillary itself *intervene* between the maternal and fœtal blood, and that interchange would have to be effected through these two

membranes; hence, to be very active it would call for considerable force for producing this.

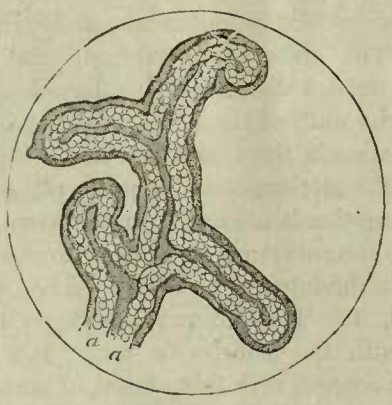

FIG. 5.—Extremity of Fœtal Tuft, from human placenta at term, in its recent condition. *A*, *a*, capillary bloodvessels. Magnified 135 diameters. (After Dalton.)

During attachment, when the sinuses are filled with the maternal blood they are greatly larger than after detachment, when the blood is forced out, and the tufts are compressed against each other in the maternal passages, reducing the placenta fully one-half its size. At the time of birth, the necks of the uterine sinuses, where they join the placenta, are readily torn through (Fig. 4, *c*, *c*, *c*, *c*), and, peeling off easily with the decidua, the organ is expelled, unless, forsooth, abnormal nutritive changes in the parts have made the union more intimate.

The problem in the mechanics concerns the manner by which the blood is speeded in and out these sinuses commensurate with the increasing wants of the growing embryo, and how this in turn is connected with the arterial and venous systems of the mother for compelling correspondence in them, the whole forming a connected movement—a movement within a movement, so to speak.

We have seen that *change of pressure is the law of the animal circulation*, and it now remains to make rigid application of this principle in mechanics to the special phenomena, anatomical and physiological, appertaining to this interesting region, in order to make them also intelligible, which otherwise are utterly inexplicable.

It follows, that for increasing circulation in the placenta we must provide for rhythmical changes in pressure, since no other force applies for producing it, and we must connect the action in the womb (which expands and contracts regularly and rhythmically) with the action in the placenta, so that when the latter expands for producing low pressure, the former contracts for producing the opposite, and *vice versa*.

In this manner an active circulation in and out the placental sinuses could be readily produced.

The following facts may be given in support of this opinion:

1. The womb must expand and contract regularly and rythmically in order to

increase circulation in the sinuses, since this is essential for changing pressure upon the blood, while the vast number of muscles and nerves in the walls of the womb are the provision for more energetic action than is possible to the placenta, which is composed almost entirely of vascular loops.

2. The womb *surrounds* the embryo, and its action would therefore be more effective for producing the changes in pressure upon it, which is also *in imitation of what takes place in the amnion* of the growing chick, it being rocked to and fro in the egg by the slow rhythmical expansions and contractions taking place in the amnion (p. 499), and by alternating this action with the one taking place in the placenta, it is readily perceived how a rapid circulation could be maintained in the maternal and placental sinuses for compelling correspondence between this and the energetic circulation in the embryo, since it all forms a connected whole. This would also be in conformity with the principle in the circulation, the blood flowing from high to low pressure. As the placenta *expands* for reducing pressure within itself, and for increasing pressure in the embryo, *simultaneously* and *pari passu* with this action the entire muscular walls of the womb *contract* for increasing pressure in the maternal sinuses for compelling this blood in the placenta, at the same time by increasing pressure upon the embryo it should determine a more rapid movement from the latter to the placenta; the one involving the other. But when the placenta contracts for increasing pressure (thereby compelling the blood out of itself in two directions, or toward the embryo and the maternal sinuses), the uterine walls *expand* for reducing pressure in the embryo and the uterine sinuses, thus greatly expediting the placental efflux; and, taking it all in all, there can be very little doubt but that the force which is represented in the muffled murmur of the placental souffle is mainly the product of the muscular uterine walls, though both undoubtedly contribute to it.

3. This action in the uterus and placenta would account for the very curious and suggestive *obliquity* in that portion of the canals connecting the uterine with the placental sinuses, being upon a line *almost parallel* with the transverse axis of the uterus and placenta, which is precisely what is called for by the special mechanics, in order to effect the lateral or to-and-fro movements, the vessels simply elongating and contracting with these, as the case may be, without interfering with the calibre of the tubes. Were the vessels straight, it would be utterly impossible to operate this mechanics, since the lateral movements should obliterate the vessels by closing the calibre. It could not be otherwise, in the very nature of things. In the accompanying diagrams (Figs. 3, 4), the vessels are represented as nearly perpendicular, but this is done simply for better definition.

4. But the strongest proof, perhaps, of this higher function of the womb is furnished in the vascular and nervous connections subsisting between it and the maternal organism. And as all this relates to circulation for building up and elaborating the embryo, obviously the mechanics for increasing circulation in the womb commensurate with that in the embryo should extend to the vessels of supply or the feeders, as also the discharging vessels, or the arteries and veins. It must be shown how this new movement, this new life set going

within the other, twines its arms around the maternal vessels and feeds itself in the measure of its necessities, by means of this pumping action in the womb and placenta which represents respiration. The spermatic and uterine arteries are the feeders (Fig. 6, *s*, *u*), while the accompanying veins are the discharging

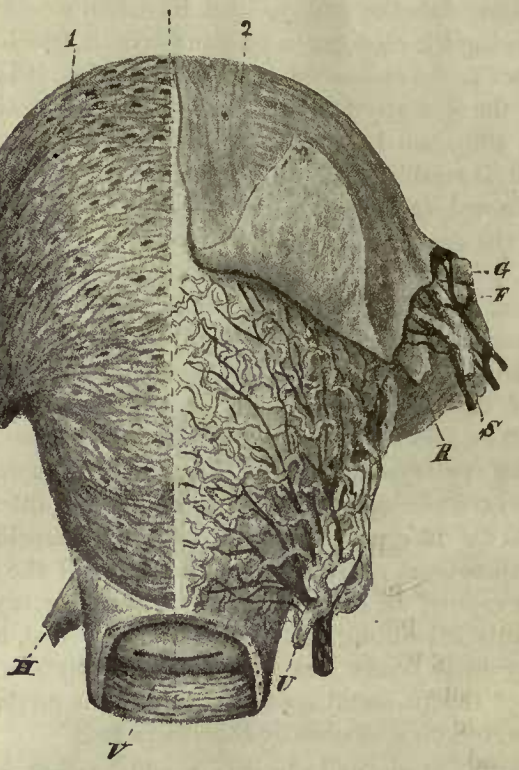

FIG. 6.—Showing the ARTERIES AND VEINS TO THE WOMB. *S*, spermatic artery and veins (ovarian); *u*, uterine artery and vein; 1, vessels passing between the muscular fibres; 2, peritonæum; *g*, Fallopian tube; *f*, ligament of ovary; *r*, round ligament; *h*, inferior ligament or duplicature of peritonæum corresponding with Douglas's cul de sac; *v*, vagina.

vessels. To this must be added the uterine lymphatics, which are very large in the impregnated womb. They terminate in the pelvic and lumbar glands. The spermatic arteries and veins have similar origin and termination, as in the male, while the uterine artery is a branch of the internal iliac, with the venous return through a vein of the same name. The deeply suggestive fact to note in this connection is that the dense plexuses of nerves to the fundus and sides of the womb *converge in the nervous ganglia* about these vascular trunks, or the spermatic and hypogastric ganglia (Fig. 7, *e*, *w*, *r*). It will be seen that the nerves to the fundus (*v*, *x*) converge in, or radiate from, the spermatic ganglion (*w*), which *surrounds* the spermatic artery and vein (*e*) (which corresponds with the attachment of the placenta), while those in the neck and sides from the hypogastric ganglion (*r*) are brought in direct relation with this ganglion by means of intercommunicating nerves (*t*) for unifying the action throughout.

Thus, nervous force to the womb is literally *banked upon the bloodvessels*,

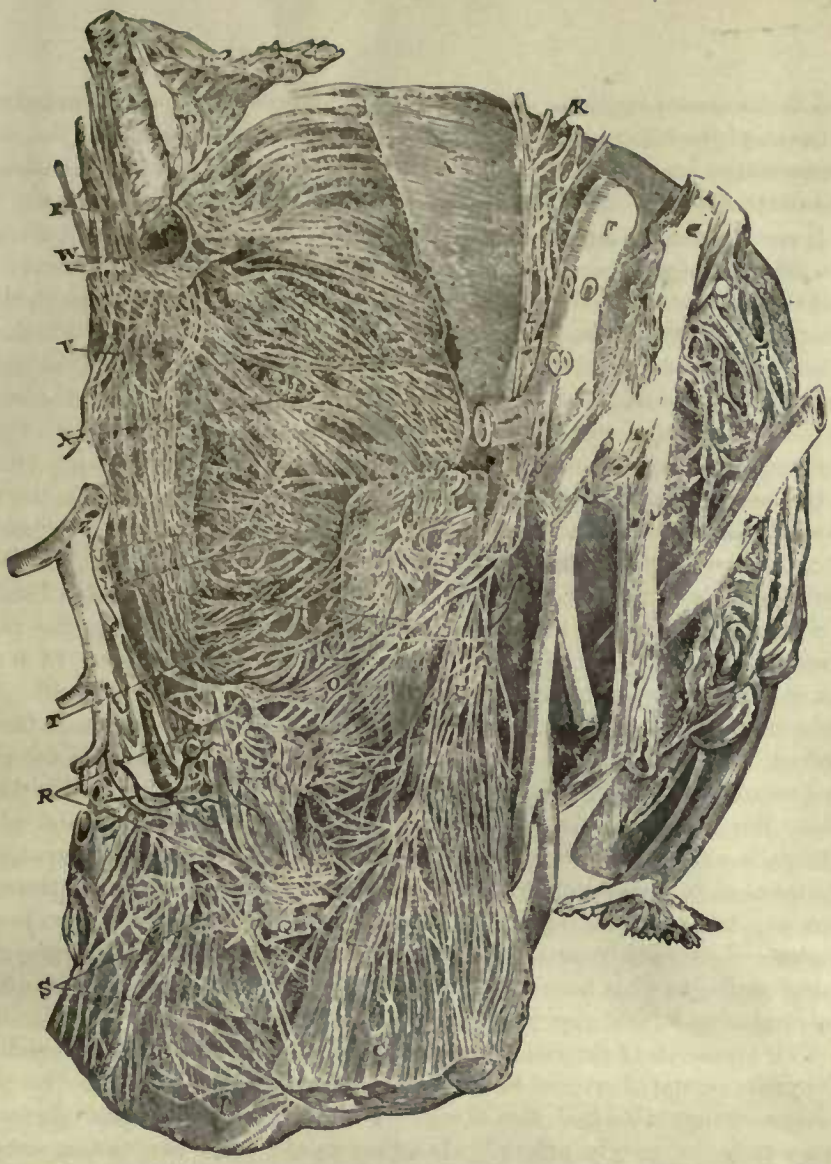

FIG. 7—Ganglia and Nerves of the Gravid Uterus at the End of the Ninth Month. *A*, the fundus and body of the uterus, having the peritonæum dissected off from left side; *b*, the vagina covered with nerves proceeding from the inferior border of the left hypogastric ganglion; *c*, rectum; *d*, left ovarium and Fallopian tube; *e*, trunk of left spermatic vein and artery surrounded by the left spermatic ganglion; *f*, aorta divided above the origin of the right spermatic artery; *g*, vena cava; *h*, trunk of right spermatic vein; *i*, right ureter; *k*, the two cords of the great sympathetic passing down along the front of aorta; *l*, trunk of inferior mesenteric artery with the nervous plexus connecting with the right and left cords of the sympathetic; *m*, the two cords of the great sympathetic at the point of bifurcation into the right and left hypogastric nerves; *n*, right hypogastric nerve with its artery injected, proceeding to neck of uterus to terminate in the right hypogastric ganglion; *o*, left hypogastric nerve as it enters the left hypogastric ganglia, and giving off branches to the left sub-peritoneal ganglia; *p*, hæmorrhoidal nerves and artery; *q*, sacral nerves entering the whole outer surface of the hypogastric ganglion; *r*, left hypogastric ganglion with the arteries injected; *s*, nerves of the vagina; *t*, nerves with an injected artery proceeding from the upper part of left hypogastric ganglion along the body of the uterus, and terminating in the left spermatic ganglion; *u*, continuation of these nerves and the branches which they give off to the sub-peritoneal plexuses; *v*, some nerves passing upward beneath the sub-peritoneal plexuses; and anastomosing freely with them; *w*, left spermatic ganglion, in which the nerves and artery from the hypogastric ganglion, and the branches of the left sub-peritoneal plexuses terminate, and from which the nerves of the fundus uteri are supplied; *x*, left sub-peritoneal plexuses covering the body of the uterus; *y*, left sub-peritoneal ganglion, with numerous branches of nerves extending between it and left hypogastric nerve and ganglia; *z*, left common iliac artery cut across and turned aside to expose left hypogastric nerve and ganglion. (After Dr. R. Lee.)

and if this means anything it means that circulation *shall* be in correspondence with the physiological requirements, or supply equal to demand, the cardinal circumstance being the *growth* and *elaboration of the embryo*, which is the object and purpose of the organ, the others being simply incidental.

It comes to this, namely, that the nervous force for expanding and contracting the uterine sinuses should expand and contract the uterine bloodvessels at *one and the same time*, thereby causing afflux and efflux of blood through them for compelling correspondence throughout which the scheme calls for. Furthermore, this would accord with the action in the vessels in respiration, as indicated by the *undulations* in arterial tension. But would not this mechanics interfere with the due circulation of blood in the *placental* sinuses? Certainly not, and for the following reasons: 1. Efflux of blood through the veins is by means of capillary vessels, which tend to retard escape, while the flow of blood in and out the placental sinuses takes place through large canals (Fig. 5, *c*, *c*, *c*, *c*). But in addition to this, the *expansion* in the placenta, which occurs during systole of the womb, should also determine the blood in this direction.

2. During diastole in the womb and its sinuses, for aspirating the placental sinuses, the *high pressure* in the arterial system causes this blood to flow into the uterine sinuses as rapidly as the blood coming from the placenta; at the same time, the valves in the veins of the uterus obviate reflux from *the venous system*. When the womb contracts for compelling the blood in the placenta and venous system, the pressure in the arterial inhibits reflux in this direction. Thus the mechanics for increasing circulation in the uterine and placental sinuses is complete in every respect, nor does it require extensive expansion and contraction in the womb in order to effect increased circulation through the sinuses, but a moderate and limited amount, sufficient only for producing *rhythmical changes in pressure upon the blood*, as must appear obvious: something similar to what takes place in the spongiæ, which have muscles (Norway) for producing a more rapid circulation in and out this canal system.

This expansion of the womb and arterial feeders would explain the sudden and enormous escape of arterial blood in post partem hæmorrhage, for the placenta being no longer attached, the flow of blood through the uterine sinuses must necessarily be purely arterial. In other words, when contraction ceases and the movement of expansion sets in, the flood-gates are thrown open to the arterial system.

In reference to the nervous centre for this pumping action in the womb, which answers to respiration in the fœtus. There can be very little doubt but that the spinal-cord functions as the common reflex centre of nervous force for producing the rhythmical expansions and contractions in the gravid womb simulating respiration. The following are the reasons for this allegation: 1. The very intimate connection subsisting between the womb and spinal cord by means of the hypogastric ganglia and sacral plexus with the intercommunicating nerves. 2. The fact that the lumbar portion of the spinal cord undergoes enlargement during gestation (Mathews Duncan). 3. The fact that reflex action in the womb is readily produced by applications to the skin surface, a circumstance well known and practised by the profession. All these facts fall readily

into line when viewed from this standpoint, and, no scientific reason existing to the contrary, we may conclude the fact as logically proven. Indeed, the gist of the question is not whether there is a reflex centre in the spinal cord for the womb, but whether this centre produces the rhythmical expansions and contractions in that organ as alleged. A full and sufficient answer to this is furnished in the fact of the total absorption of the relative phenomena, anatomical and physiological, which otherwise are utterly inexplicable, underneath all which is the organic law on which animal life itself is constructed, calling for rhythmical changes in pressure in the contents of the gravid womb and in the uterine sinuses for increasing circulation. Nor is it reasonable that the enormous number of muscles and nerves in the womb are for compelling out the contents at the end of the term simply, but, on the contrary, that they perform an active and essential part in the work of construction which precedes expulsion. Beyond a shadow of a doubt, they are not idle in all this while, especially when supreme necessity would have it otherwise; on the contrary, they are *evolved as force is needed* for carrying on circulation, while at the end of the term they are available for assisting in expelling the embryo, hence perform an active *role* from the beginning to the end of their existence, as is ever the case with the muscles and nerves.

One other circumstance in this connection, namely, the very *tortuous* course of the arteries in the womb (Fig. 6), which undoubtedly is adjustment with this action, permitting the rhythmical expansions and contractions to take place without involving any strain to the vessels. The veins, it will be perceived, take a straight course, while the arteries are serpentine or bent upon themselves. This is due to the fact that the veins are more extensile, and possess greater powers of elongating and shortening than the arteries, the yellow elastic coat of the latter tending to limit their actions. It will be remembered that this circumstance has forcible illustration in the splenic artery and vein, the former being almost twice the length of the latter, to allow for expansion in the stomach when food is taken, otherwise this would involve prodigious strain to the vessels, with great reduction of the calibre. But the same remark will apply to the vessels of all the hollow viscera. Thus everything is in correspondence. Of course, the arc of movement in the womb and placenta is necessarily more limited than in the lungs, in which considerable space is required for sucking in the air simultaneously with the venous blood, but which would not apply for the fœtal circulation, as the oxygen is furnished by arterial blood at *one and the same time* with the nutritive and force-producing elements, which the scheme calls for in order to generate force, since it is by a combination of the two that force is evolved. The inclusion of the intestines with respiration by means of the pneumogastric nerves has its explanation in this circumstance, as has been fully set forth in the preceding pages. Differentiation in the organs cannot, for obvious reasons, work any change in the fundamental principle underlying the mechanics for increasing circulation, which is by rhythmical changes in pressure involving a pumping action for compelling the commerce in the bloodvessels and expelling waste products, while the *speed* of the currents thus produced is determined by the rapidity and energy of the rhythmical ex-

pansions and contractions pervading the organs, inclusive of the heart and vessels, since it all forms a connected movement for increasing circulation between the cell brood and environment, from which everything is obtained and into which the waste products are returned, the two going on simultaneously.

With the expiration of the intra-uterine term, expansion of the maternal passages sets in for reducing resistance to the egress of the embryo, and the womb and abdomen contracting simultaneously for increasing pressure in the womb, the contents are compelled out in the environment. Here, as elsewhere, *the law of pressure applies for compelling movement in the contents of the hollow viscera for which special adjustments obtain in the organs and organism*, the underlying principle being *rhythmical changes in pressure.*

The atmosphere being invisible, it is difficult to realize the important relations this sustains to the mechanics, nevertheless, the fact is incontrovertible, that from centre to circumference, and from surface to surface of the body it is corner-stone and foundation to *all the mechanics concerned in circulation.*

It is passing strange the matter should have escaped attention so long, especially in this age, when *thought* is reaching down into the organic basis of life. Indeed, one needs to go there if he would unravel the tangled skein in animal structure and function, since the definite arrangements that obtain in the organs with every stage in development show unmistakably a common relation to fundamental forces in nature underlying it all, notably *pressure and gravitation.* The animal body is not *outside* and *independent* of the organic laws, but, on the contrary, is in entire conformity with them, while the arrangements which obtain in the structures represent the relative adjustments for special work.

RESPIRATION IN THE NEW-BORN: THE CHANGE IN MECHANICS WHICH THIS INVOLVES.

The first thing in the new-born is to start respiration for compelling in the commerce in the environment in place of the uterine sinuses, and the action in the placenta for which this is the substitute, the oxygen passing in by way of the lungs and the aliment through the intestinal canals. But this requires fresh adjustments in the mechanics of circulation to bring it in correspondence with this circumstance, notably, circulation of the blood in the lungs, and the attaching of the intestinal apparatus to this movement by means of the nerves connecting in the medulla oblongata, a matter which has already been fully considered in the preceding pages. The first thing, therefore, is to start respiration, when it will be in order to consider how the mechanics in circulation swings into this pendulum movement for compelling correspondence throughout, with the blood ever flowing from high to low pressure in conformity with the organic law underlying the organism itself. One end of the nervous system, so to speak, is *spread out* in the skin surface, the other through the organism, while the medulla oblongata functions as the common centre to it all; any impression, therefore, made upon the skin surface is promptly reflected to the medulla oblongata, thence over all the structures for producing the reflex actions connected with respiration and circulation. The irritations attendant upon parturition from friction against

the maternal structures are calculated to produce these reflex actions; but the contact of the sentient surface with the stimulus in the atmosphere itself would also excite it. And if the child should be injured by the rude experiences incidental to parturition, a yet more powerful means for exciting the reflex actions connected with respiration is furnished by the sudden application of cold to the surface, as in sprinkling cold water upon it, * or a sudden, sharp slap with the open hand may be substituted instead, as is commonly practised. Last, but not least, carbonic acid, as it accumulates in the blood, acts as a special stimulus to respiration. It cries out in pain, and, presto! the hæmal mechanics is changed. The low pressure which is produced in the alveoli by expansion of the lungs during inspiration compels *simultaneous* afflux of air and blood in the alveoli; while the high pressure which is produced by the subsequent contraction during expiration causes *simultaneous* efflux in these fluids, which flow from high to low pressure in conformity with organic law—the one flowing out by reflux action through the route of ingress, the other passing into the left chambers of the heart and arterial system on its way to the cell-brood, as has already been described in the air-breather. This abandonment of the old route for the new is readily explained, since it is in strict accordance with physical law, being in the direction of least resistance.

For example, we *begin* the mechanics with high pressure in the arterial system, since this extends through the ductus arteriosus to the semilunar valves of the pulmonary artery, the floor of support to the arterial column. Hence, when the alveoli expand during inspiration for sucking in air through the trachea, the high pressure in the pulmonary artery and ductus arteriosus compels this blood to flow straight on to the low-pressure areas in the alveoli *simultaneously* with the afflux of air, or in the direction of least resistance, in place of forcing its way in the arterial system against high pressure, which would be contrary to law. And the ductus arteriosus, though still filled with blood, as in the case of an artery, beyond the ligature to where a collateral branch is given off, shrinks and contracts till it becomes a solid, impervious cord.

For closing the foramen ovale the following mechanics apply: After birth the inpour of blood in the left auricle by way of the pulmonary veins is as rapid as it is in the right auricle through the venæ cavæ, and pressure is at equilibrium in the two auricles, which at once suspends all tendency in the blood to pass from one side into the other during auricular diastole; whilst during the auricular systole and the high pressure this produces in the auricles causes this blood to flow into the expanding ventricles, where low pressure invites it, the same applying for either auricle. But gravitation also should compel it in this direction, since the ventricles are *under* the auricles. Thus a dual force applies (suction and gravitation) for compelling this blood in the ventricles during the auricular systole, and the foramen ovale, being thus abandoned, is closed and obliterated by membranous formation.

But in intra-uterine life the matter is different; here the whole blood is

* The intimate connection subsisting between the respiratory centre and the skin surface is of easy demonstration in the adult by the same means. For example, every impact of cold water against the skin produces spasmodic inspiration or expansion in the lungs; not deep, however, but very energetic.

poured into the right auricle, that from the upper cava passing at once in the right ventricle, while that in the lower cava (which includes the blood from the umbilical vein) passes through the right into the left auricle, with which it directly communicates, guided by the Eustachian valve, but also pushed over and deflected in this direction by the weight of the descending current from the upper cava; but if the head be downward then by its own weight the blood would gravitate in this direction, the influx of blood from the upper cava also compelling it. And with the absence of blood as a *counter-force* in the left auricle this blood is necessarily compelled in the latter, thence in the left ventricle and aorta, while that in the right ventricle passes in the arterial system at the aortic arch by way of the pulmonary artery and ductus arteriosus. After birth, however, the pumping action in the lungs reverses all this in manner as above described. The pulmonary artery in the embryo, in place of discharging through the lungs, left auricle and ventricle, empties its blood at once into the aorta as it passes under the arch, and which is also in the direction of least resistance, since it is impossible for this blood to thread its way through the capillary meshes of the *unexpanded* alveoli. This circumstance has forcible illustration, even in the air-breather, and when the alveoli are filled with residual air, by simply inhibiting inspiration by closing the mouth and nose so as to prevent expansion in the lungs, the blood, in consequence, rapidly accumulating in the right side of the heart and venous system. In the space of a minute there is lividity of the lips and whole cutaneous surface from venous stasis in the systemic capillaries. If longer than this, an appalling venous suffusion pervades the surface; in the face most, for this is the most vascular portion, with the large venous trunks in close proximity to the heart. Even the eyes are forced outward, becoming prominent from distension of the intra-orbital veins caused by obstruction in the cavernous and lateral sinuses. But the instant the obstruction is removed and the lungs are permitted to expand the dammed-up blood surges through the alveoli, and all runs on as before. In other words, the heart and vessels are unable to carry on circulation in the absence of the pumping action in the lungs, for which afflux and efflux of air is essential. But all this has been sufficiently explained.

INCUBATION. CIRCULATION IN THE EGG.

Why should there be an air-chamber to the egg (Figs. 8 and 9)? We are now prepared to furnish a scientific explanation to this physiological problem, otherwise inexplicable, viz., the contents of the egg for developing the chick is enclosed by a firm unyielding wall of living marble, and since the animal circulation is dependent upon rapid rhythmical changes in pressure, it follows that provision should be made *within* the shell for effecting this, otherwise the action in the heart and vessels could not take place. This air-chamber (*g*), together with the important relations it sustains to circulation and elaboration in the growing chick, organilogically, therefore, must be regarded as one of the most essential and important elements in egg-structure, the underlying principle to all the nutritive changes which are ushered in under the action of external temper-

ature. The accompanying illustration (Fig. 9) will serve to impress the matter.

The discipline in the nutritive processes requires the blood to be brought from the vitellus and aërated in the allantois, thence to be dispatched through the body territories. Accordingly two great venous trunks (omphalo-meseraic veins), one in each fold of the splanchnopleure, embracing the vitellus, are the

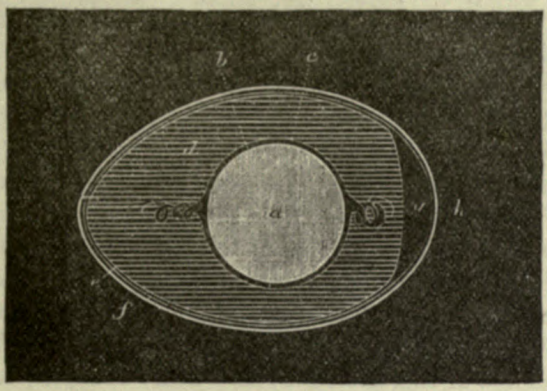

FIG. 8.—Diagram of Fowl's Egg. *A*, yelk; *b* vitelline membrane; *c*, chalaziferous membrane; *d*, albumen; *e*, *f*, middle and internal shell membranes; *g*, air chamber; *h*, calcareous shell. (After Dalton.)

first evolved, while at the terminal ends or confluence the heart is formed by the blending of the walls of these venous trunks.

According to His, the heart is developed by the coalescence of a layer of the splanchnopleure with a similar layer from the somatopleure, the hollow cavity formed by the union being in free communication with the adjacent omphalo-

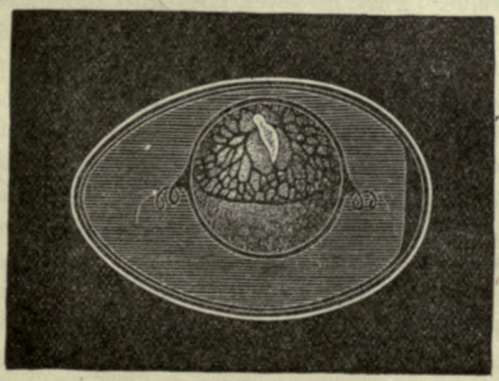

FIG. 9.—Egg of Fowl in Process of Development, showing area vasculosa, with vitelline circulation, terminal sinus, etc.

meseraic veins. According to Foster and Balfour "the upper end of the heart is developed out of the mesoblast of the splanchnopleure," but "increases in length step by step at the expense of the continually coalescing omphalo-

meseraic veins." Thus the fact is undeniable, that the heart is developed in the *venous system in connection with the vitellus.* The rhythmical expansions and contractions in this organ (the *punctum saliens* of early authors) serve to pump the vitelline fluids in the bulbus arteriosus and the two aortæ which are developing at the other end of the heart. But for this air-cushion within the egg (Figs. 8 and 9, *g*), neither these rhythmical expansions in the heart nor the changes in pressure for compelling circulation in the vitelline fluids could take place, since the unyielding shell would inhibit these actions, as must appear obvious.

Respiration is provided for in the following manner: The allantois (a diverticulum of the intestinal canal) is pushed out around the amnion which contains the embryo, and expanding its vast capillary net-work of vessels (whose footstalks spring from the two iliac arteries, as do the umbilical arteries in the mammalian embryo) against the shell-membrane or chorion becomes the respiratory organ of the chick, by means of which the venous blood is constantly arterialized, the oxygen passing in and the carbonic acid passing out through the pores in the shell by the action of the polar forces. But "at the time the heart first begins to beat, the capillary system of the vascular and pellucid areas is not yet completed, and the fluid which is at first driven by the heart contains, according to most observers, very few corpuscles. . . . . The course of the blood then, during the latter half of the second day, may be described as follows: The blood brought by the omphalo-meseraic veins falls into the twisted cavity of the heart, and is driven thence through the bulbus arteriosus and aortic arches into the aortic trunk. From the aorta by far the greater part of the blood flows into the omphalo-meseraic arteries, only a small amount passing on into the caudal terminations. From the capillary net-work of the vascular and pellucid area into which the omphalo-meseraic arteries discharge their contents, part of the blood is gathered up at once into the lateral or direct trunks of the omphalo-meseraic veins. Part, however, goes into the middle region of each lateral half of the sinus terminalis, and there divides on each side into two streams. One stream, and that the larger one, flows in a forward direction until it reaches the point opposite the head, thence it returns by the veins spoken of above, straight to the omphalo-meseraic trunks. The other stream flows backward, and becomes lost at the point opposite the tail."*

The following from the same authors is deeply suggestive: "Soon after its formation the heart begins to beat, at first slow and rare pulsations, *beginning* at the *venous* and passing on to the arterial end. It is of some interest to note that its functional activity commences long *before* the cells of which it is composed *show* any *distinct differentiation* into *muscular or nervous elements.*" It would be difficult to overestimate this circumstance, since it establishes beyond peradventure the power in the higher as in lower animals to effect rhythmical expansions and contractions in the soft tissues in the absence of any muscle or nerve for producing them. But at present the significance of these rhythmical expansions and contractions taking place in the heart concerns us most, since the manifest purpose is to increase circulation; and as this can only be done by

* Foster and Balfour's "Embryology."

pumping the blood of the omphalo-meseraic veins, it follows that both expansion and contraction is necessary for accomplishing this, the one for aspirating this fluid, the other for propelling it. This would explain why the action should *begin at this end of the heart.* Of course, as the area of circulation increases it would call for corresponding increase of force for effecting it. Accordingly, *pressure is increased* for facilitating circulation at the same time that additional force is placed upon it; notably, the former is produced by the amniotic fluid and the latter by the action in the amnion.

The amnion closes around the embryo of the chick on the fourth day, and on the fifth fluid begins to collect in the sac, and by the seventh the embryo is submerged in a considerable quantity of water. "By the seventh day very obvious movements begin to appear in the amnion itself: slow vermicular contractions creep rhythmically over it. The amnion, in fact, begins to pulsate slowly and rhythmically, and by its pulsations the embryo is rocked to and fro in the egg. This pulsation is due, probably, to the contraction of involuntary muscular fibres, which seem to be present in the attenuated portion of the mesoblast, forming part of the amniotic fold" (Foster and Balfour).

The physiological significance of this accumulation of amniotic fluid, and the rhythmical contractions and expansions in the amnion, may not be doubted for a single moment, since the former would increase pressure, while the latter should produce the necessary changes in pressure in the embryo for compelling respiration and circulation to be in correspondence with the nutritive and functional processes in the growing chick, both of which are constantly extending their limits and requiring more and more force for effecting them. These slow pulsations in the amnion of the chick answer to the placental and uterine souffle in gestation, the principle being precisely the same. How otherwise explain this circumstance? But, as has already been remarked, *all pulsations relate to changes in pressure*, and these pulsations in the amnion, together with the amniotic fluid, relate to changes in pressure in the embryo for increasing circulation of the juices.

The explanation of the mechanics is sufficiently easy; notably, there are two cardinal points from which to regard it—one in the allantois, the other in the embryo. First, commencing with the movement of expansion in the allantois. The increase in pressure which this produces in the embryo through the amniotic fluid should cause the venous blood to flow with increased energy towards the allantois, the point of low pressure within the egg (the heart and vascular system, of course, assisting in this); the contraction or condensation of the amnion, by relieving pressure in the allantois, enables this to expand *pari passu* with contraction in the amnion for aspirating the venous blood, at the same time that it aspirates the air through the outer membrane and pores of the shell. When the movement is reversed by expansion of the amnion, the reduction in pressure which this effects in the embryo, together with the simultaneous increase of pressure it produces in the allantois by forcibly compressing this against the shell wall, causes the aerated blood in the latter to flow with augmented speed into the heart of the embryo, as also through the tissues of the

latter; since the blood vascular system would be less embarrassed and be more free to act in consequence.

But the allantois itself also participates in this action, the fluid it contains enabling it to effect such rhythmical compression of the capillary plexuses

FIG. 10.—Diagram of Young Embryo and its Vessels, showing circulation of umbilical vesicles, and also that of allantois, beginning to be formed. (After Dalton.)

(Fig. 10). The following forcible illustration (Fig. 11) by the distinguished biologist at Jena will serve to impress the matter. At this early stage in development (third week in gestation), it will be seen that pressure is increased at the cardinal points, namely, vitellus (*a*), the body of the embryo (*c*), and allantois

FIG. 11.—Human Embryo in the Third Week. *A*, large globular yelk-sack; *b*, allantois; *c*, amnion; *d*, tufted chorion. There are yet limbs. (After Haeckel.)

(*b*). As the embryo and allantois are elaborated out of the material in the vitellus, this would explain the greater accumulation of fluid in this locality for compelling circulation toward those two points, whilst the rhythmical contractions of the yelk sac should greatly expedite it. For increasing circulation

between the embryo and allantois (*c*, *b*), commensurate pressure is produced by accumulation of fluid in these two points or poles of the circulation. This, together with the action in the membranes themselves, and the heart and vessels, is sufficient for carrying on circulation in the initial stages of embryonic evolution; but with the increase of growth comes increasing difficulty for effecting it; hence the pumping action which is set up in the placenta and womb, together with the accumulation of amniotic fluid for transmitting these actions upon the embryo, as described above. Thus, everything is in correspondence—the liquor amnii, the increasing growth of the placenta and the number of muscles and nerves in the walls of the womb—and so continues till the close of pregnancy. In other words, it all forms a connected whole in the mechanics of the embryonic circulation.

In the case of the bird, the allantois answers to the placenta, since it pumps in both oxygen and nutriment; only that the pumping action in the abdomen (the soft hinder parts of the bird) for pumping air and blood through the alveoli, is set up in the latter days of incubation, when rapid atrophic changes soon obliterate the umbilical vessels, and, breaking the now attenuated and fragile shell-wall with its beak, it finally makes its escape, leaving the allantois and atrophied membranes behind.

MODE OF GRAFTING THE OVUM IN THE TISSUES OF THE WOMB.

In *mammalia* the ovum is not discharged from the maternal passages, but is retained in the expanded oviducts at the point of juncture, which answers to

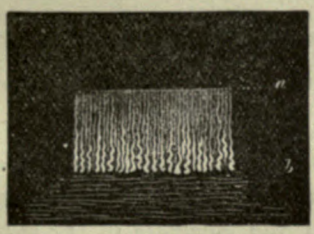

FIG. 12.—A VERTICAL SECTION FROM THE UTERINE MUCOUS MEMBRANE, showing the numbers and position of the tubules. *A*, free surface; *b*, attached surface. (After Dalton.)

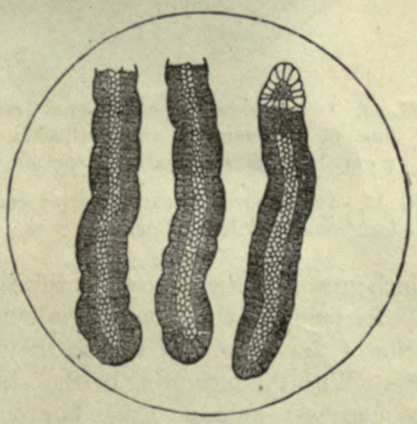

FIG. 13.—Same tubules, greatly magnified. (After Dalton.)

the womb, where growth and elaboration are effected through the vascular connections established between it and the maternal circulation. Briefly, the mode of closing this is as follows: The uterine mucous membrane is virtually but a dense mass of single, straight follicles, arranged perpendicularly to the free surface (Figs. 12, 13), and with the closed end resting against the muscular

walls of the womb. At intervals, fine bloodvessels course up between them, and, reaching the mucous surface, surround the tubules with a capillary network. But when fecundation is effected vascular turgessence at once sets in, producing rapid growth and development of the membrane—of the follicles especially; and, coming in contact with this highly vascular and tumified surface as it leaves the Fallopian tube, the ovum is rapidly incorporated with it, by means of the shaggy villosities which are thrown out from the outer surface (Fig. 14, *a*.),

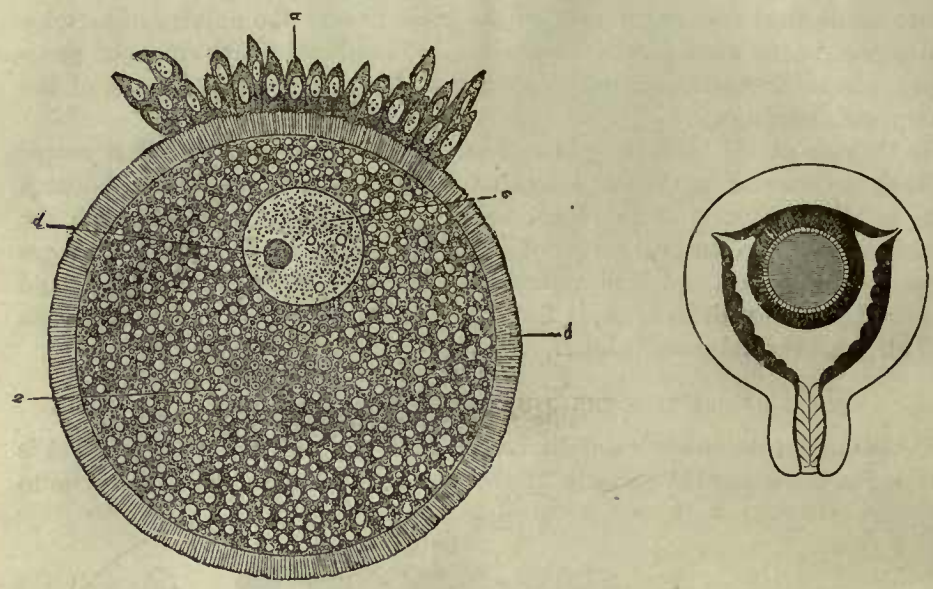

FIG. 14.—OVUM OF THE RABBIT, from a Graafian follicle $\frac{1}{50}$ of an inch in diameter. *A*, epithelium of the ovum; *b*, zona pellucida, with radiating striations (vitelline membrane); *c*, germinal vesicle; *d*, germinal spot; *e*, vitellus. (After Waldeyer.)

FIG. 15.—IMPREGNATED UTERUS, showing connection between villosities of chorion and decidual membranes. (After Dalton.)

which grow into the expanded orifices of the tubules, and function as temporary villi for pumping the abundant albuminous secretions of the glands in the interior of the ovum. Of course, they contain all the elements of tissue structure. With the ingrowing of the shaggy tufts of the chorion in the follicles, the mucous membrane expands around the ovum for bringing the follicles in contact with every portion of the chorion till the whole is completely enclosed, forming what is known as *decidua reflexa*, while that portion of the membrane with which it first came in contact, in immediate relation with the muscular walls, constitutes *decidua vera*, the part that enters the structure of the placenta which is subsequently formed. At this time the villosities of the chorion project into the uterine follicles in every direction (Fig. 15), but as growth proceeds, and more and more nutriment is needed in the embryo, the villi in relation with *decidua vera* become vascular, while those in relation with *decidua reflexa* are atrophied, in consequence of which this portion of the chorion becomes bald. Finally, the transformations which occur in the placenta

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convert the tubules into placental sinuses, and the villi of the chorion into vascular loops, surrounded and embraced by the lining membrane of the sinuses, like the fingers of a glove (Fig. 16), as before remarked; but since the capillary loops are projected in the villi, the natural inference is that the walls of the latter coalesce with the walls of the sinuses to form this intervening membrane. In this manner the embryonic and maternal structures are inseparably blended.

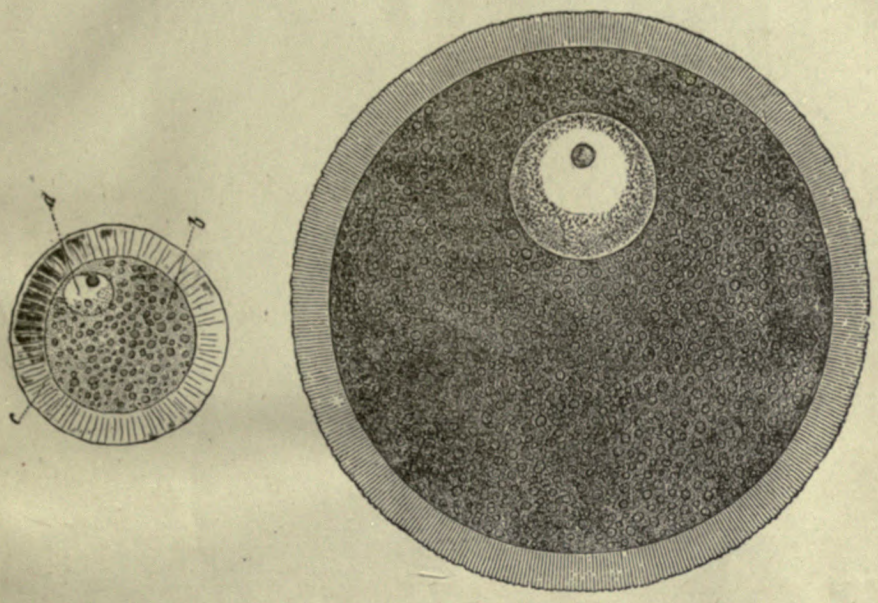

FIG. 16.—Ovum from the Mole. *A*, nucleus; *b*, cell body; *c*, thickened corpuscle traversed by pores. (After Leydig.)

FIG. 17.—The Human Egg from the Ovary of the Female: much Enlarged. The entire egg is a simple, globular cell. The greater part of the spherical egg-cell is formed by the egg-yelk, or the granular cell-substance (protoplasm), which is composed of innumerable delicate yelk granules, with a little intervening substance. The germ-vesicle, answering to the cell-kernel (nucleus) lies in the upper part of the yelk. It contains a dark nucleolus or germ-spot. The globular mass of yelk is surrounded by a thick transparent egg-membrane (*zona pellucida* or *chorion*). This is penetrated by the pore-canals, in the form of very numerous hair-like lines, which run rapidly towards the centre of the globe; through these the thread-shaped, moving sperm cells pass, in the process of impregnation, into the egg-yelk.

The common relation which animal life sustains to the organic laws has forcible illustration in the very ova, the structure being fundamentally the same (Figs. 16 and 17). The absence of a shell wall permits expansion in the chorion *pari passu* with the growth of the embryo, while the womb expands in concert with this action in the chorion and embryo.

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